NATIONAL RADIO INSTITUTE

Complete Course in PRACTICAL RADIO

NRI

Radio-Trician

(Trade Mark Registered U. S. Patent Office.)

LESSON TEXT No. 5

(3rd Edition)

AUDIO-FREQUENCY AMPLIFIERS AND RADIO-SPEAKERS

Originators of Radio Home Study Courses
··· Established 1914 ···
Washington, D. C.

"Whoever neglects learning, loses the past and is dead for the future."
—*Euripides.*

REGULARITY IS THE KEY TO RELIABILITY

A Personal Message from J. E. Smith

Physical fitness depends a great deal on the regularity of the bodily functions. Physicians tell us that we should eat our meals at regular hours, that we should set aside a certain period each day for exercise and recreation. In this way we attain our maximum health. Mental regularity is not so easily achieved, although it can be acquired. There are many disturbing influences. It is difficult to have a fixed time and place for study and then stick to it. But once it is accomplished, study is easier and more efficient.

Reliability is the direct result of regularity. The man who is regular in his habits can be depended upon. Others can predict what he will do and when he will do it. He can depend upon himself. Students fail to get their work done because they cannot rely upon themselves to study when the time comes. Make yourself regular to make yourself reliable. Mental and bodily regularity will go a long way in determining your success.

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Complete Course in Practical Radio

NATIONAL RADIO INSTITUTE WASHINGTON, D. C.

AUDIO-FREQUENCY AMPLIFIERS

The usual audio-frequency amplifier uses iron-core transformers to couple the tubes together. But there are several ways in which the several stages can be connected together without using transformers. The first of these methods which we will consider is the resistance-capacity coupled amplifier, or as it is called more generally, the *resistance coupled amplifier*.

RESISTANCE COUPLED AMPLIFIERS

A circuit diagram of this type of amplifier is shown in Fig. 1. For the sake of clearness we have omitted the "A" batteries, for these are always connected in the same way.

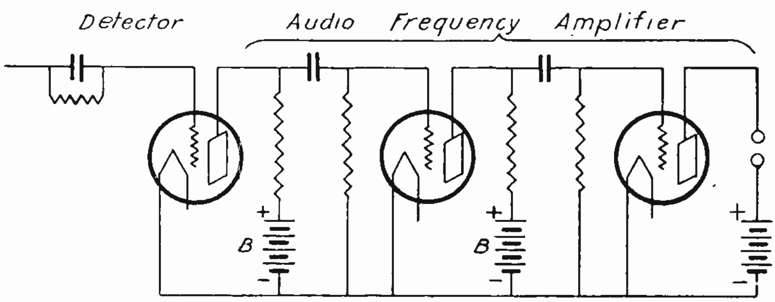


Fig. 1—Elementary Circuit Diagram of a Two Stage Resistance Coupled A. F. Amplifier.

We have shown the amplifier connected to the output of a detector tube. Now let us see how this amplifier works. In order to do this, we will have to start with an electron tube, and build up the complete amplifier. Then we will know the reasons for the different things in the circuits. Suppose we start with an electron tube, having its filament lighted by an "A" battery, so that it emits electrons, and we place in the plate circuit a resistance of about 100,000 ohms and a "B" battery. We have shown this part of the circuit in Fig. 2-(A). Now suppose we have a signal voltage (that is, an alternating or oscillating voltage) impressed on the input of the tube. This is indicated by the letter "v."

As we learned before, when we have such a state of affairs there will be a similar current in the plate circuit of the tube, but of course made stronger or amplified by the tube. In other words, there will be a rising and falling voltage established between the points "a" and "b" of Fig. 2-(A), which we want to make work for us. The idea is now to take this voltage between "a" and "b," and impress it on the input of another electron tube so as to amplify it still further. Suppose we were to connect the points "a" and "b" directly to the input (this is, the grid and filament) of another electron tube. We have shown this in Fig. 2-(B). What will happen? The answer is that the second tube will not work at all. The reason for this is clear, for we are using a voltage of 90 volts, or perhaps 135 volts in the "B" battery, and this is connected in Fig. 2-(B) just like a "C" battery, that is, in the grid-return of the second tube. Having such a high positive grid voltage, the plate current in the second tube will be so greatly increased that the tube will not work. Under such conditions the tube will be *saturated,* by which we mean that when the grid or "C" voltage is so *positive,* a weak signal voltage on the grid will produce no corresponding voltage change in the plate or output circuit.

What we must do is to get rid of this high voltage on the grid of the second tube. This is easily done by placing a fixed condenser in the grid circuit of this tube, as shown at Fig. 2-(C). This condenser is marked "C." A constant voltage, such as furnished by the "B" battery will not pass through the condenser, but a varying voltage, furnished by the radio signals, will pass through easily. Therefore the condenser C *blocks* the voltage of the "B" battery off the grid of the second tube. For this reason, the condenser, when used in this way is called a *blocking condenser.* But remember that it allows the signal voltage to pass through onto the grid of the second tube, where we want it to go.

Now we can ask again, "Will this work"? The answer is again "No." Why will this system not work yet? This brings up something which we referred to in our previous lesson, but which we said we would explain a little more in detail later on. You will remember that the grid of an electron tube is directly in the path of the electrons which are travelling from the filament to the plate of that tube. On account of this, if the grid were left "free," that is, not connected to anything which furnishes a complete path around to the filament, it would collect a number of these electrons, and so acquire a large negative charge. In an ordinary circuit this charge could pass off the grid by flowing around through a coil and back to the filament. In other words there would be no chance for a fairly large negative charge to accumulate on the grid.

But when we place the blocking condenser in series with the grid of the second tube in Fig. 2-(C), we are preventing these electrons, and the negative charge which they cause on the grid, from flowing off the grid. As a result the grid becomes highly charged negatively. Now you remember what happened a few moments ago before we placed the blocking condenser in the circuit. The "B" battery placed such a large

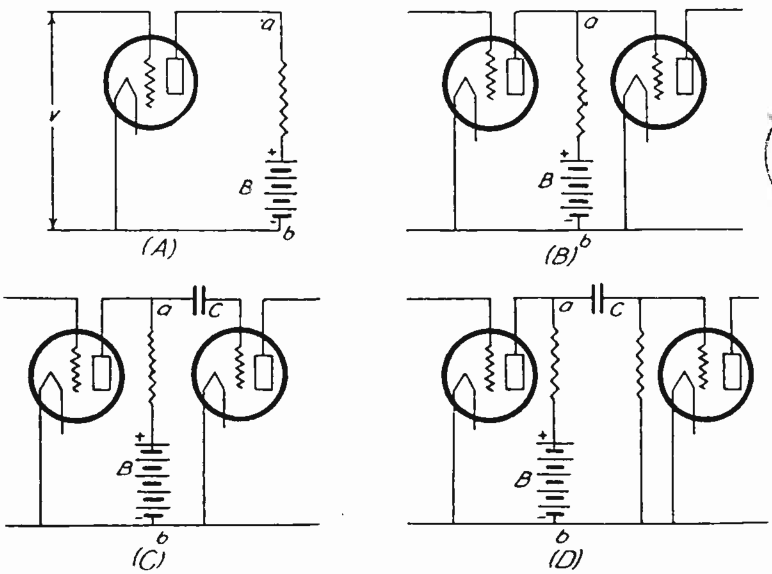


Fig. 2

positive charge on the grid that the plate current was increased so much as to saturate the tube so that it would not operate. The opposite occurs when the negative electrons charge up the grid. The plate current is reduced so far that the tube will not work. Naturally we cannot expect the tube to work with hardly any current in the plate circuit. But suppose we furnish a path over which these electrons can escape from the grid back to the filament from whence they came? That is just exactly what we have to do before the system will work well. We can do this by inserting another resistance between the grid and filament of the second tube, but this time it must be a very large resistance. If it is not large, a considerable part of the signal voltage will be used up in it. In actual practice, this resistance is about 500,000 ohms. The resistance used in the plate circuits of the tubes is about 100,000 ohms, and the capacity of the blocking condenser may be anything from about .01 to .1 microfarad. (A microfarad is one-millionth of a farad). It is not well to use less than this, as the low tones will be lost in the amplifier, and if we use too large a capacity, there will be other ill effects encountered. We will learn more of this later on.

We can now see the complete circuit, as shown in Fig. 1, more clearly. This is a combination of several stages of the circuit explained in Fig. 2. Going a little farther, we have in Fig. 3, the complete circuit, where only one set of "B" batteries is used. This circuit can be used to replace any other kind of audio-frequency amplifier that may be used in the receiver. But you must also know that whereas two stages

Resistance Coupled Unit and a Three Stage Resistance Coupled Amplifier.

are all that are required in an amplifier which uses transformers, there are generally three stages required in a resistance coupled amplifier. For this reason three stages are shown in Fig. 3. Even when three stages are used, the amplification in a resistance coupled amplifier is generally less than that obtained in a transformer coupled amplifier, but it is often claimed that better quality of reproduction can be obtained by using a resistance coupled amplifier. This may be true when the amplifier is properly designed, but when not properly designed, the resistance coupled amplifier may give as poor quality of reproduction as the poorest transformer coupled amplifier.

A "C" battery is generally placed in the grid circuit of the last tube to prevent distortion and reduce "B" battery consumption, because no high resistance is in the plate circuit and therefore it receives practically the full applied "B" voltage.

IMPEDANCE COUPLED AMPLIFIERS

We will now go further into the different kinds of audio-frequency amplifiers. We have so far studied the transformer coupled and the resistance-capacity coupled amplifier. The next type that we shall take up is known as the *impedance coupled amplifier.* The complete circuit of this amplifier is shown in Fig. 4. With a little study you will be able to see

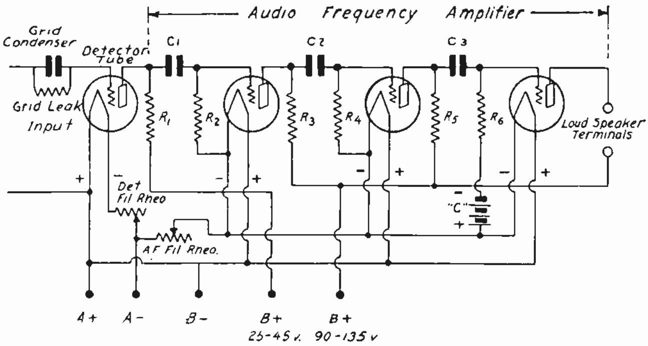


Fig. 3—Circuit Diagram of a Three Stage Resistance Coupled A. F. Amplifier.

that this circuit is exactly the same as the circuit for the resistance-capacity coupled amplifier. The difference is not in the wiring diagram, but in that we use an *impedance coil* in the plate circuits of the three tubes, instead of resistances. There is still the blocking condenser, and there is also the grid-leak resistance, just as in the resistance coupled ampli-

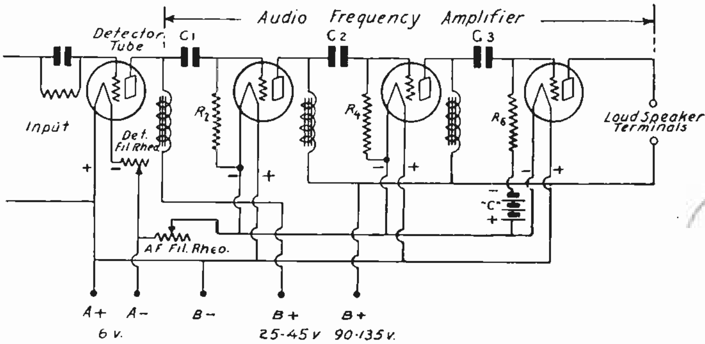


Fig. 4—Circuit Diagram of a Three Stage Impedance Coupled A. F. Amplifier.

fier. The simple circuit of the impedance coupled amplifier is shown in Fig. 5-(A), and in Fig. 5-(B) the resistance-capacity coupled amplifier, so that you can see the difference between the two systems.

Since there is no difference in the circuit arrangement, it is to be expected that there will be no difference in the operation of the set. This is true to a great extent as there is no difference in the operation of the two systems excepting in one respect. You will probably remember that we have said before that the resistance does not change as the frequency of the current changes. There is this much in its favor, that no matter what the frequency may be, when we have a certain voltage impressed on the input of the first tube, we shall always have a similar voltage established across the terminals of that resistance in the plate circuit of the tube.

In other words, if we have a certain voltage "v," as in Fig. 5, impressed on the input of the tube, there will be a certain voltage between the points "a" and "b" in the plate circuit of that tube. This will be the same thing, whether the frequency of the impressed voltage "v" is 50 or 5,000 cycles per second. This is because the resistance does not change with the frequency.

But there are difficulties encountered in using resistances in the plate circuits of the tubes. In order to operate the electron tubes properly it is necessary to have a certain voltage on the plates of these tubes. Now you will see, if you look again at Fig. 5-(B), that the "B" battery is connected in series with this resistance, so that the electrons flow from the filament to the plate through the resistance, then from the battery back to the filament. In order to obtain a considerable amount of amplification in each stage it is necessary to use a large resistance in the plate circuits, perhaps 100,000 ohms. This is the value of the resistance often used.

As part of the "B" battery voltage is used up in this large resistance, *it is generally necessary to use somewhat higher "B" voltages in resistance coupled amplifiers than in transformer or impedance coupled amplifiers.*

To come back to the impedance coupled amplifier, let us first find out what is an *impedance coil.* One of these is shown in Fig. 6. You will see that an impedance coil is nothing more than a transformer which has only one winding instead of two. In other words, an impedance coil consists of a core of iron, over which is wound a great many turns of fine wire. There may be as many as 5,000 turns of No. 36 wire, or there may be more turns. In many cases the wire may be as small as No. 40 B. & S. gauge.

Now we have said before, that when an alternating current is passed through a coil of wire, a varying magnetic field is created which cuts back on the turns of wire, and *induces* a voltage across the terminals of the coil. What we do then, in the case of the impedance coupled amplifier, is to take this voltage across the terminals of the coil, at the points "a" and "b" in Fig. 5-(A), and impress it on the input of the next tube, through the blocking condenser. You remember in the case of the resistance coupled amplifier, we had to place this blocking condenser in series with the grid in order to keep the high voltage of the "B" battery away from the grid; then, after

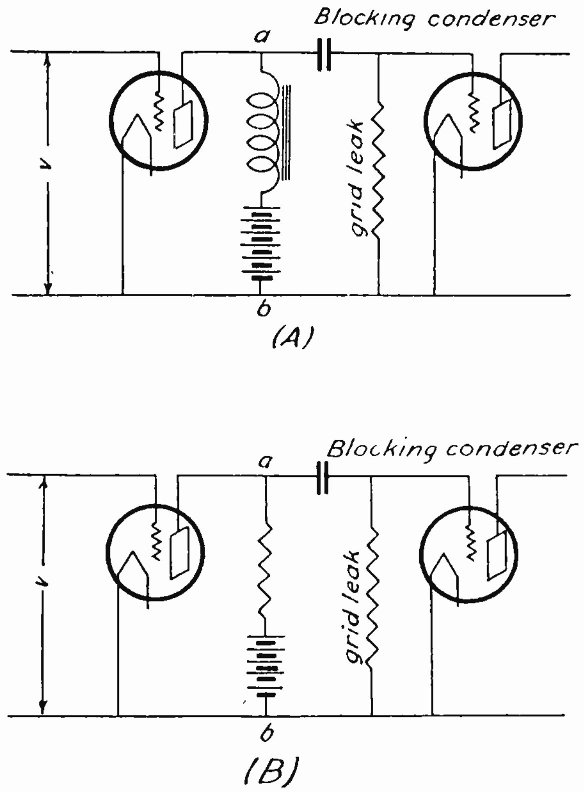


Fig. 5

doing this we had to add a grid leak resistance to the circuit so that a large negative charge would not collect on the grid. The same is true of the impedance coupled amplifier.

But now we have an impedance coil instead of a high resistance, in series with the "B" battery. The impedance coil has only a small resistance compared with the other, say about a couple of hundred ohms, so that it is not necessary to use a very high "B" battery voltage in order to get the proper amount of current flowing or to get the proper voltage on the plate of the tube.

The varying voltage, which is due to the signal put into the amplifier and continuously *varies* in strength, will produce a relatively large voltage between the points "a" and "b" of Fig. 5-(A). You see, we have to draw a very distinct line between varying and constant currents. A constant current has very little effect on an impedance coil, and this is due to the small resistance of the coil. The smaller this is, the better the coil. But the varying current has a large effect on the impedance coil, and furthermore, this effect is different at every frequency. The lower the frequency the smaller is the effect, and the higher the frequency the greater is the effect.

On account of the fact that the effect of the signal voltage is small at the lower frequencies, say from 200 cycles per second down, it is difficult for the amplifier to amplify sounds which have such low frequencies. The quality of reproduction, therefore, is made poor on this account. Just to give you an idea of what we mean, suppose you think of a man playing a piano, and suppose that this man has a weak left-hand and a strong right-hand. The low notes of the piano will come to your ears very softly then, and his playing will not sound well. But if his hands are equally strong the music will sound very much better.

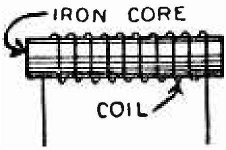
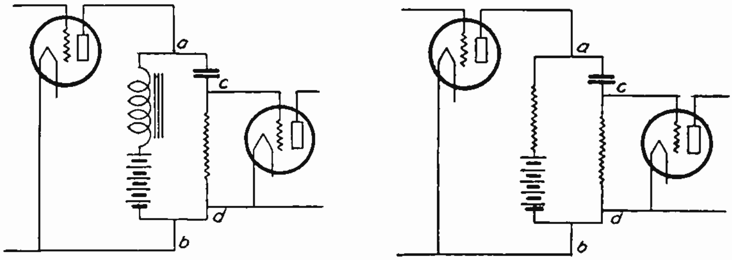


Fig. 6—Impedance Coil.

So, in any kind of amplifier, if we should lose the low notes the quality of reproduction will be poor. Both impedance coupled amplifiers and transformer coupled amplifiers have this one defect in common; they are both poorer on the low notes than on the high notes. But if the primary winding of the transformer, or the winding of the impedance coil, has a great many turns of wire, and the iron core used in these is large enough, it is possible to make this weakening of the low notes hardly noticeable. In other words, in order to make the quality of reproduction good, it is necessary to use rather large impedance coils and transformers. Of course, we have to draw the line somewhere, and strike a happy medium between perfect reproduction and the size and cost of the coils.

In addition to these things, you will remember that we once said that some of the strength of the low-frequency notes is also lost in the blocking condenser, and that this must be made fairly large so that the loss is not noticeable. All these things must be considered together when designing or building an amplifier, for it is clear that it would be a foolish trick to buy a very large and expensive impedance coil in order to get good quality, and then spoil it by using a small blocking condenser. The blocking condenser in either the resistance coupled amplifier or the impedance coupled amplifier should never be less than .01 microfarad, and preferably should be greater.

We must now consider another defect of these two systems; this defect leads us to another type of amplifier called the *dual impedance* amplifier, which has been devised in the effort to correct this defect. Although we connected the grid



(A) Fig. 7 (B)

leak resistance in the circuit so that the grid of the tube would not accumulate an excessive negative charge, there are two things that this grid resistance may do. The first of these is that when we are receiving a very strong signal, as from a local broadcasting station, the grid may collect quite a large negative charge in spite of the leakage path provided by the resistance. When this happens, the tube is said to be *blocked,* and the quality of reproduction will be badly spoiled. Of course, it is possible to reduce the volume of the loud-speaker by any of the means provided in the radio receiver, but the operator of the set does not always want to do this, especially if the receiver does not give sufficient volume in the first place.

The other effect which we mentioned is a little more complicated and we must study it carefully. Suppose we look at Fig. 7. The circuit diagrams in this figure are the same as the circuit diagrams in Fig. 5, only they have been drawn a little differently. You can see that they are similar by comparing the two sets of diagrams, line for line. The same points "a" and "b" have been marked on these diagrams as were marked on Fig. 5.

Now you remember we had a certain voltage between the points "a" and "b" due to the signal voltage. This voltage is across the terminals of the plate resistance or the impedance coil, depending upon which type of amplifier we are using. As you can see in the diagrams of Fig. 7, this same voltage is at the same time across the blocking condenser and the grid resistance, since these two are connected to the same points. But also notice that the second tube is only connected across the grid resistance, and we want the voltage input to this tube to be as great as possible. It is clear that part of the voltage between the points "a" and "b" is used up in the blocking condenser, and this cuts down the amount of voltage that we can get on the input of the second tube.

In order to increase this voltage, two things might be done, though both of these lead to difficulties. The first is that we may use a very large blocking condenser, as we suggested before, but a very large condenser leads to still other difficulties. The second thing that we might do would be to increase the grid leak resistance. But this will lead to the same difficulty we tried to avoid by putting the grid leak there in the first place. If the grid leak resistance is too high it will be difficult for the electrons to leak off the grid, and consequently the grid will become highly charged.

So, in trying to avoid these difficulties, the grid leak resistance is removed, in the *dual impedance* amplifier, and another impedance coil substituted in its place. The circuit diagram of the dual impedance system is shown in Fig. 8. By using the second impedance coil instead of the grid leak resistance, there is hardly any chance for a charge to collect on the grid of the second tube, no matter how great we make this impedance. The greater we make it the greater will be the amplification up to a certain point. And also the greater we make it, the better will it amplify the low notes. This impedance, as well as the one in the plate circuit, still has that same defect of passing on the low notes less effectively than the high ones. But if the system is properly designed it is possible to make the reproduction good enough to satisfy very discriminating ears.

There is an important thing that must be remembered in connection with all these kinds of audio amplifiers, and that is, that first, there is a certain amount of amplification in the tube itself, as we learned quite a way back. In the transformer there is also a certain voltage *"step-up,"* so that the transformer coupled amplifier can furnish a considerable amount of amplification.

On the other hand, although we still have the same amplification in the tube itself, in the other systems, such as the resistance or impedance or dual impedance systems, there is never a voltage step-up in the instruments connected between the tubes. In fact, there is always a step-down, or a loss of amplification in these systems. Consequently the amplification obtained in any stage of these types of amplifiers, is always slightly less than that which the tube itself furnishes.

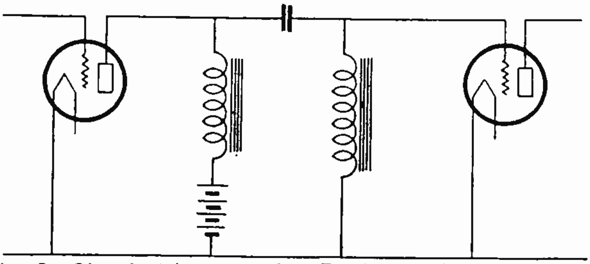


Fig. 8—Circuit Diagram of a Dual Impedance Amplifier.

In spite of this small amount of amplification as compared with that which the transformer coupled amplifier will give, and also in spite of the fact that three stages of resistance, impedance or dual impedance amplification are required to give a fair amount of volume, as compared with two transformer coupled stages, it is often claimed that the improvement in the quality of reproduction is worth the additional stage. It is safe to say, however, that any one of these systems, transformer coupled or otherwise, can be made so good, when properly designed, that there will be little to choose between in the matter of quality of reproduction.

To go a little farther in our discussion of amplifiers, there is another type which is a combination of the dual impedance and the transformer coupled amplifier. No special name has been given to this type, but it is shown in Fig. 9. It consists of a transformer having two windings exactly alike; in other words, the *turn-ratio* of this transformer, as it is called, is *one to one*. There is also a blocking condenser C shown in the circuit of Fig. 9. However, the grid charge can easily leak off through the winding of the transformer marked S. This type of amplifier has been found to give slightly more amplification than the resistance or impedance types, and there is little or no chance of blocking the tubes.

You have probably noticed the great similarity among all these types of amplifiers. The circuit diagrams of all, with the exception of the transformer coupled amplifier, are exactly the same; that is, the scheme of connections is exactly the same. To review briefly some of these similarities and differences therefore:

(a) The filament circuits of all the tubes are the same with the exception of the detector tube, when using a grid condenser and grid leak. In this case the grid-return is made to the positive side of the "A" battery. When using a "C" battery detector the grid-return goes to the negative side of the "A" battery.

(b) All the radio-frequency amplifier stages are wired alike.

(c) The wiring scheme of the radio-frequency amplifiers is almost the same as that of the audio-frequency amplifier stages, the main difference being that there are no tuning condensers in the audio-frequency amplifier.

(d) All the stages of the audio-frequency amplifier are alike, excepting in the case of the "B" battery voltages. The first stage of the audio-frequency amplifier is generally operated on 90 volts of "B" battery and the second stage either on 90 or 135 volts or more. When plate voltages higher than 45 are used, it is necessary to use "C" batteries in the grid circuits of the tubes. A "C" battery is often used even where only 67.5 volts are used on the plate. The following "C" battery voltages may be satisfactorily used, when using the UX-201A type of tube:

"B" battery voltages	67.5	90.	135
"C" battery voltages for above values......	3.	4.5	9

It is often necessary to use appropriate "C" voltages on the various tubes in audio-frequency amplifiers, whether they be of the transformer coupled type or of the type that we have been discussing. The method of applying the "C" voltages in the transformer coupled amplifier has been shown in a previous lesson. The manner of applying the grid bias (or "C" voltage) in impedance and resistance coupled amplifiers is shown in Fig. 8-A. The "C" voltage is simply connected to the resistance or impedance which furnishes the path over which the electrons leak off the grid. There is no loss of voltage in the grid leak, on account of the fact that the "C" voltage on the grid is always negative and no current is flowing through the grid leak. There is simply a "charge" placed on the grid by the "C" battery. Without any current flowing through the resistor, there cannot be any voltage drop, hence there is no loss of voltage in it, and the

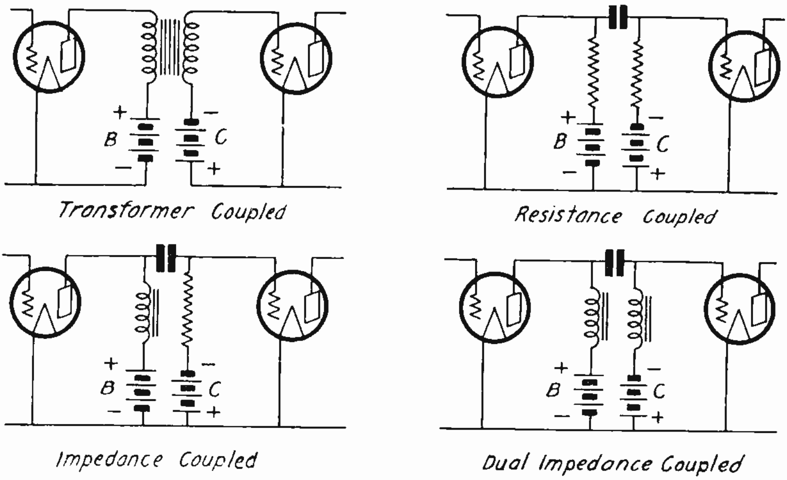


Fig. 8-A.

"C" voltage at the grid is the same as the voltage of the "C" battery.

(e) With the exception of the transformer coupled amplifier, all other types of audio-frequency amplifiers are wired exactly alike. The only difference is the substitution of an impedance for a resistance, either in the plate or in the grid circuit, or in both circuits.

(f) The wiring of the "B" batteries remains the same, the positive terminal of the "B" battery always being connected to the plates of the tubes, and the negative terminal connected either to the negative or to the positive side of the filament, depending upon the particular design of the radio receiver. When connecting up a radio receiver it is advisable to try either connection, and to use the connection which gives the best results. But when making the trial, be sure that you have the tubes out of the sockets, otherwise you are apt to burn them out. First remove the tubes, then connect the batteries. Next place your fingers across the two springs of the tube socket which make contact with the filament prongs of the tubes. If you do not feel a slight electric shock (which will not hurt you) you may put the tubes in the sockets with safety.

We have by this time, gone a considerable distance in our general study of radio. You will probably remember that the main purpose of these first six lessons of the course is to give you a bird's-eye view of the whole radio situation. It must be clear to you that it is impossible to completely cover the whole study of radio in six lessons. But the idea is that when you come to the lessons that will follow the first

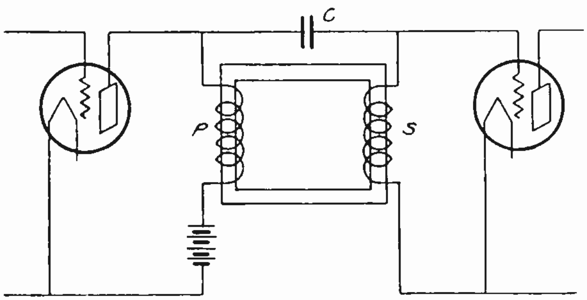


Fig. 9—Circuit Diagram of a Combination Dual Impedance and Transformer Coupled Amplifier.

six, you will find them much easier and more understandable than they would be if you had not already learned what it was all about. Besides all this, this course in radio is a *practical* one; we must train you in as short a time as possible, so that if you wish, you may actually go into the radio business, after the first few lessons have been learned, and during the rest of the course you may "Earn as You Learn."

For these reasons, there are several things which we have not yet met in our study, which we must introduce here, in spite of the fact that we will not be able to go into them very deeply at present. Later on whole lessons will be given over to these ideas separately; but in the meantime you will know what it is all about, and you will actually be able to work with these various kinds of receivers, and, if you wish, do servicing or constructional work, or perhaps selling of such receivers.

REGENERATION

The thing we are going to learn about now is called "*regeneration*." In order to introduce it to you we shall have to go back to our old idea of the water tanks and pumps, and the rest of it. The scheme shown in Fig. 10 may probably be a very useless one in connection with pumping systems, but it will serve well to explain what we have in mind.

Suppose, then, we have a stream of water which enters the tank on the left at the point marked "a." If the valve at the bottom of this tank is properly adjusted, we can get the water to rise in the first tank to a certain level, as indicated at m, m, and then after that the valve can be regulated so that the water flows out at the bottom of the tank (at b) just a little faster than it flows into the tank at "a."

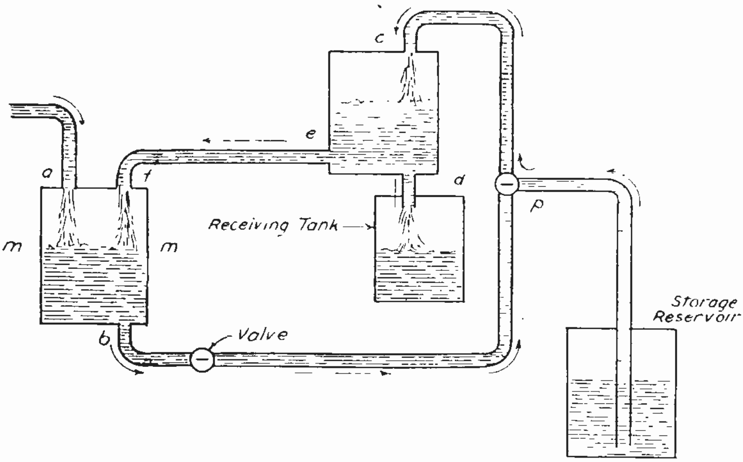


Fig. 10

In other words, we have the energy of the radio waves entering the system at the point "a," this energy is stored up in the condensers and coil (in other words, in the first tank), and is then passed on to the rest of the circuit, in this case, the electron tube (or the pump). Now you will notice that we have the water flowing out slightly faster than it flows in. This is similar to what happens in a radio circuit. Part of the energy which comes from the radio waves is used up in the resistance of the circuits.

But now the water passes on from the outlet "b" to the pump marked "p." This pump is like the electron tube. It pumps the water which has passed the valve, up to a higher and larger tank, and at the same time this same pump lifts water up out of a storage reservoir, to help fill the higher and larger tank. In the radio circuit we have the same thing; the electron tube draws energy out of the "B" batteries (that is, the storage reservoir), and by so drawing on this reserve energy, amplifies the weak signals which came in originally.

On account of this additional energy brought into the system by the pump, it is possible to fill up the larger tank, which represents the next electron tube in the circuit. The water enters this second tank at the point marked "c."

Next, we can draw off the water from this second tank and allow it to flow into a receiving tank underneath, at the point "d." This receiving tank represents a detector, or any kind of system which would make the radio-frequency signals audible (that is, capable of being heard).

So far so good; we have at least got the system working. But now suppose that some mischievous boy should come along, and connect a small hose at the bottom of the second tank at the point "e," and would connect the other end of this hose to the first tank at "f." It is clear that some of the water which we pumped around the circuit, would flow back again through this hose.

You remember that at first the water level in the first tank was dropping slowly, the water was running out faster than it ran in. But now, there is more water flowing in, for we have two streams entering the tank, one at "a" and the other at "f." As a result, the water level in the first tank drops more slowly.

Of course, the water level in the second and higher tank would drop more rapidly, but the pump makes up for this, and pumps the water up out of the storage reservoir faster, since we will suppose that it automatically makes up for the loss as the water flows out through the hose.

As a result, the water flowing through the hose is pumped around and around the system, and is continually added to by the water being pumped up out of the storage reservoir, so that the water level in the second tank is now higher, and we can draw more water out of it, to put into the receiving tank. So you see, having this automatic pump, when the boy thought he was doing a little mischief, he really was helping us out. But remember that only this automatic pump made this possible.

In other words, when we apply this to our radio-frequency amplifier, if we take a little of the energy in the plate circuit of a tube, and send this back into the grid circuit of the tube, it will combine with the energy of the incoming signals. The tube will then amplify both the incoming energy and the additional energy returned from the plate circuit, so that we shall have a much greater current flowing in the plate circuit than we would have had without this small return of energy to the grid circuit (or the input of the tube.)

Referring again to Fig. 10, in the beginning, the water level in the first tank was getting lower and lower. This corresponds to a loss of energy in the tuned-circuit. After some of the water is returned, the water level drops more slowly. In the radio circuit, the return of a little energy from the plate to the grid circuit makes up for part of the energy loss in the resistance of the tuned circuit. This effect is called *regeneration*. In radio receivers it is found that a little regeneration can amplify the strength of a weak signal enormously; without regeneration we can expect a signal to be amplified perhaps only about 3 to 5 times in each stage of the radio-frequency amplifier. But when we introduce regeneration the amplification may go as high as perhaps 15 or 20 per stage.

In Fig. 10, if we take out the hose (e f), and put in a larger hose, we shall have more *feed-back*, and the "regeneration" will be greater. That is, as we increase the amount of water "fed back," the water level in the tank drops more slowly, until we can go so far as to keep the water level from dropping at all. In other words, the *feed-back*, as it is called, has made up for all of the energy losses. This is called *critical regeneration*, and in a radio receiver is that condition which furnishes the *greatest* amount of amplification in a radio-frequency amplifier.

Now, suppose we go a little farther, and make the feed-back so great that the water level in the first tank not only does not fall, but *actually rises*. In other words, we are *more than making up* for the losses in the system. Then if the energy is fed back under sufficient pressure, and the first tank becomes entirely full of water, the water will actually *oppose* the water coming in, and, working against it, may actually *flow out* of the tank at "a" instead of flowing *into* the tank.

In the radio receiver, when the feed-back becomes great enough to *more than make up* for the losses in the resistance of the circuits, the tube is said to oscillate and it now acts as a small transmitter, because just as the water was forced *out* of the *intake* pipe at "a," the fed back energy will be forced out into the antenna circuit, and the receiving set then acts like a radio transmitter (of small power, of course) and can actually be used to transmit radio signals over short distances.

Of course, when this condition occurs, we cannot receive concerts with the receiver. We have to so adjust the receiver that we never increase the feed-back any further than the point of *critical regeneration,* in fact, we must always operate the receiver at a point slightly lower than this. This is the condition at which the receiver is most sensitive, and will tune in the most distant stations.

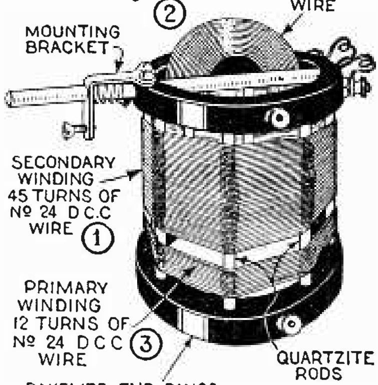


Fig. 11—Three Circuit Tuner.

Now that we have some idea of what regeneration means, let us find out how we get regeneration in radio receivers. In some cases we actually do *not want* regeneration, but we shall learn about these particular cases later on. The most popular receiver in which regeneration is purposely used in order to make the receiver very sensitive is known as the *three-circuit tuner.* In this receiver the regeneration is made to occur in the detector circuit. The circuit of the three-circuit tuner is shown in Fig. 12. In this illustration we have shown only the circuit of the *regenerative detector,* and an audio-frequency transformer connected in the output. Any of the audio-frequency amplifiers which we studied a little while ago can be added on to this circuit at its output.

This circuit differs from the ordinary detector circuit only in one respect, the plate circuit of the tube has been broken at the point "A," and at this point a coil is connected, marked T in the diagram. This coil is known as the "tickler" coil. The primary winding is P, the secondary winding is S and the ticker coil is T. The primary and secondary coils are fixed, that is, they cannot be moved, but the tickler coil is movable, so that the operator can adjust the amount of feed-back to suit his needs. A photograph of the three-circuit tuning coil is shown in Fig. 11.

To show how it works: the plate current flows through the tickler coil, and since the secondary coil S is in the magnetic field of the tickler coil, a voltage is *induced* in the secondary coil by the plate current flowing in the tickler coil. This is the old, old story again of a varying current producing a varying magnetic field, and when this varying magnetic field cuts another coil (such as the secondary), it *induces* a varying voltage in this second coil. Notice how many times you come across this same thing. You will find it many times before you are finished with this course.

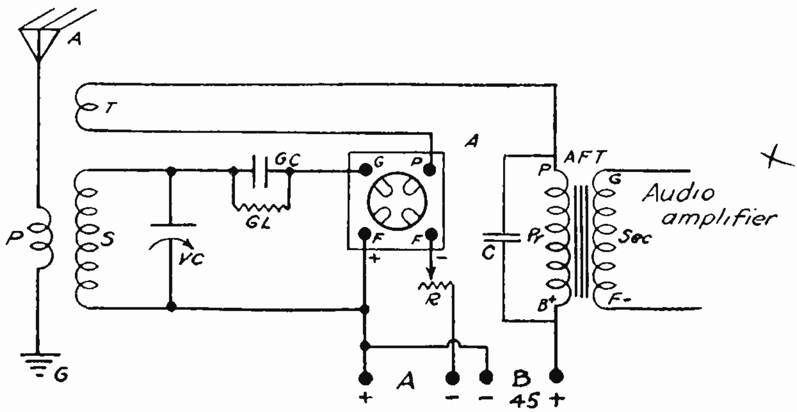


Fig. 12—Circuit Diagram of a One Tube Regenerative Set, Using a Three Circuit Tuner.

This "*feed-back*" of voltage unites with the voltage due to the signal, and the two are amplified together, thereby producing a stronger signal current in the plate circuit. There is one other thing about this circuit that we must call to your attention, and that is the by-pass condenser C connected across the primary winding of the amplifier transformer. This may or may not be necessary, depending upon the design of the transformer. The way to determine whether or not it is needed is to try the set with and without it. Connect it whichever way the set works best. The capacity of this condenser is usually .0005 to .001 mfd.

There is also regeneration in the radio-frequency amplifier, even though we have not tried to put it there purposely. Under certain conditions, which we generally have in radio-frequency amplifiers, we do not need a tickler coil to feed back the energy; the tube itself can do this. You will remember that in the tube we have three elements or electrodes—the *plate*, the *grid* and the *filament*. Any pair of these form a small condenser, since a condenser is merely composed of two metallic conductors such as these are, separated by a small space. Consequently some energy from the plate circuit can be fed back to the grid circuit through the small condensers formed by these tube electrodes. The action is really a very complicated one, but as we have stated before, we shall study it later on in another lesson.

For the present, however, this will be sufficient. But as we also said before, we must have some means of controlling this regeneration, so that the receiver will not *oscillate* and become a transmitter, instead of a receiver of radio energy. One method of doing this is to use a *potentiometer* in the grid-

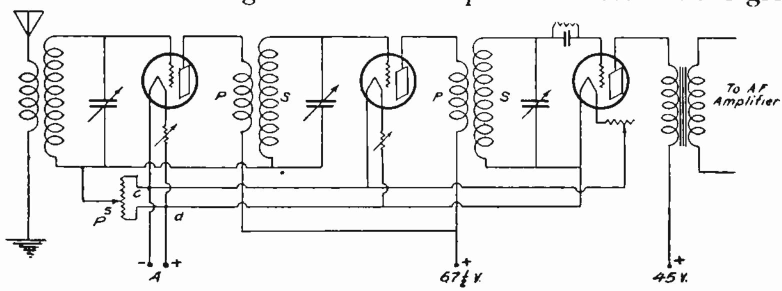


Fig. 13—Circuit Diagram of Two Stages of Tuned Radio-Frequency Amplification and Detector, Using Potentiometer to Control Oscillations.

return circuits of the electron tubes in the radio-frequency amplifiers. This is shown in Fig. 13. The potentiometer is marked "P." The only difference between this circuit and the radio-frequency amplifier of Fig. 15, Lesson 4, is that in the latter, the wires at "a" and "b" have been disconnected from the filament. Then these wires, called the grid-returns, are connected together and joined to the slider, or the movable arm, of a potentiometer. This is marked "s" in Fig. 13. The two other terminals of the potentiometer are then connected to the filament terminals, as at "c" and "d" in Fig. 13.

The idea of using the potentiometer is this: in the first place a potentiometer is nothing more than a resistance having a terminal at each end. There is also a slider or movable arm which can slide over this resistance, making contact with it at any point we wish. A photograph of one of these is shown in Fig. 14, and a diagrammatic sketch in Fig. 15. The two ends of the potentiometer are connected to a battery, as at "c" and "d" in Fig. 13 they are connected to the "A" battery.

The voltage across the points "x" and "y" of Fig. 15, is therefore the same as the voltage of the battery, and by moving the contact we can take off the potentiometer any voltage we care to up to the entire voltage of the battery. For instance, if the battery has a voltage of 6 volts, and we move the slider down half-way, the voltage between the point "x" and the slider will be one-half of 6 or 3 volts. Then, by connecting the slider to the grid-returns of the tubes, we can place on the grids of the tubes whatever voltage we need to control the regeneration. For you must remember that if we place a positive charge on the grid of a tube, it will cause the plate current to increase, and this with other effects that we shall learn later on, will control the regeneration.

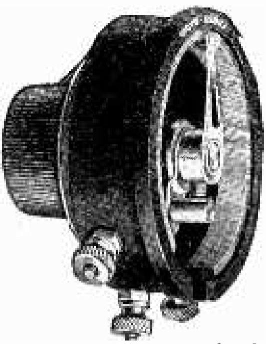


Fig. 14—A Standard Potentiometer.

As for entirely preventing the circuits from oscillating, that is, from passing the condition of critical regeneration, there are several ways in which this may be done, but for the present the simplest, and perhaps the most effective way is to use only a few turns of wire on the primaries of the radio-frequency transformers. These primary coils are connected in the plate circuits of the radio-frequency amplifiers, as at P in Fig. 13. The primary coils are marked P and the secondary coils are marked S.

LOUD-SPEAKERS

We will end this lesson with an explanation of what the loud-speaker does and how it does it. You will probably remember that several lessons back we learned that when a current flows in a coil of wire, a magnetic field is established in and about the coil. You also learned that this magnetic field can act like any other magnetic field, the main thing being, at the present time, the fact that such magnetic fields can attract pieces of iron. This principle is used in the ordinary telephone receivers, which you use every day, and in certain types of loud-speakers which use "units" as they are called, just like the telephone receiver. The word *unit* is often applied to the working part of a loud-speaker, in order to make it clear that when speaking of it we are not talking about the *horn* or *bell* of the loud-speaker. A loud-speaker is composed of two parts—the unit, and a part which acts on the air in front of the unit.

Suppose we look at Fig. 16 to see what it is all about. In this illustration we have shown a very simple form of a loud-speaker unit. First, we have a permanent magnet. In the case shown, this has a simple cylindrical shape, but in many units the permanent magnet has a horse-shoe shape. Above this permanent magnet is an iron diaphragm, which is supported on a ring, which is generally backed up with a rubber gasket or washer.

Now, since we have a magnetic field surrounding this permanent magnet, and this magnetic field passes into the iron disc which we call the diaphragm, it is clear that the iron

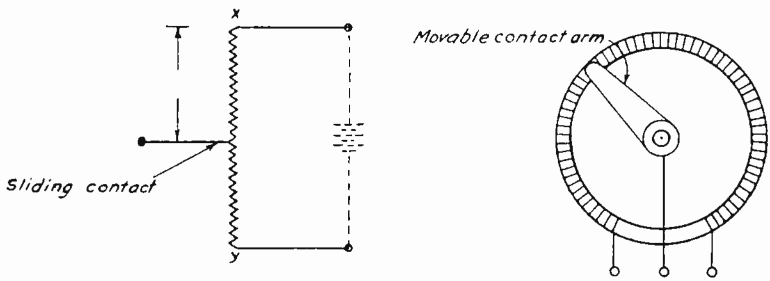


Fig. 15

diaphragm must be attracted to the magnet. Such is the case, and as shown in Fig. 17, the diaphragm is bent downward, into the position marked B. Remember, this bending is due *only* to the *permanent* magnetic field.

Now, suppose, for some reason or other, the magnetic field is made weaker. Then the diaphragm will not be bent as far, for there is a springiness in it which tends to keep it flat. Suppose that the magnetic field were made stronger by some means or other. Then the diaphragm would be bent still further, or to the position A. Of course, the amount which the diaphragm is bent, under any circumstances, is very small, perhaps only a few thousandths of an inch, but in order to illustrate it clearly, we have had to exaggerate the bending in Fig. 17.

Now, when the diaphragm is bent in this manner, every time it moves one way or the other, it either has to push the air in front of it, or suck the air after it. Consequently, if this pushing and pulling takes place fast enough, we shall have established in the air beyond the diaphragm, a series of air waves, which have spots of high pressure and spots of low pressure, one after the other, corresponding to the pushes and pulls of the diaphragm. These high and low pressure spots occur one after the other, and are at an equal distance from each other, this distance being a *quarter of a wave-length,* and the number of high pressure or the number of low pressure spots is the same as the *frequency* of the air waves. This idea is pictured in Fig. 18.

Here we have the diaphragm, and the dotted lines show the two positions when the diaphragm is pushed or pulled by the magnet. The high pressure spots are represented by the heavy shading, and the low pressure spots by the light shading in the picture.

The next thing to consider is, how do we make the diaphragm vibrate back and forth, under the influence of the

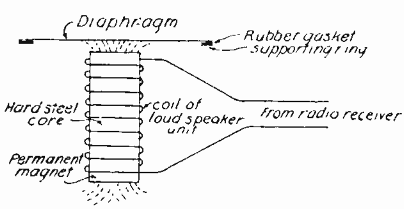


Fig. 16

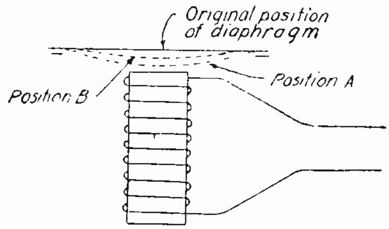


Fig. 17

magnetic field. So far we have considered only a permanent magnet, which always has a *constant* or a steady magnetic field, and therefore has always a steady attraction for the diaphragm, so that the permanent magnet by itself could not make the diaphragm vibrate.

A few moments ago we said that in order to make the diaphragm vibrate we had to make the magnetic field stronger and weaker in regular succession. There is a simple way to do this, as you may have already guessed by looking at the coil of wire in Figs. 16 and 17. The coil is wound around the permanent magnet. In manufacturing, these coils are first wound on small bobbins of fiber or of bakelite, which are then slipped onto the permanent magnet.

Now suppose we pass into this coil an alternating signal current which we may get from the output circuit of the second audio-frequency amplifier tube of our radio receiver, and is a current which varies in frequency and intensity in just the same manner as the sounds we want to hear. This alternating current reverses in direction a certain number of times a second, according to its frequency. Therefore, when we pass this current into the coil of the loud-speaker unit, it creates a magnetic field of its own, the strength of this field depending upon the intensity of the alternating signal current.

While the current in the coil is flowing in one direction, it sets up a magnetic field which is in the same direction as the field of the permanent magnet, and hence, aids it in attracting or bending the diaphragm. When the direction of the current changes, the polarity of its magnetic field changes also, and this time opposes the magnetic field of the permanent magnet. Consequently, the pull on the diaphragm is decreased and it springs back a little.

In other words, the diaphragm will spring back and forth as the current in the coil of the loud-speaker unit changes

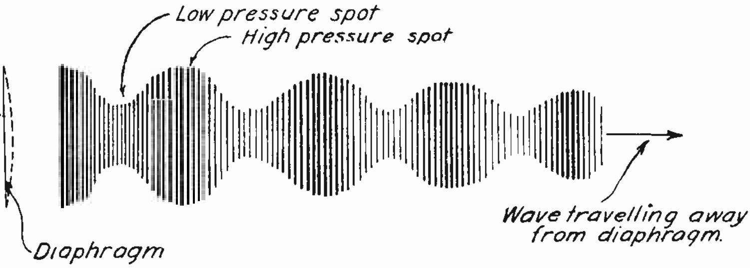


Fig. 18

its direction of flow, and these vibrations of the diaphragm will occur exactly in step with the reversals of the current. If the current reverses a thousand times a second, the diaphragm will vibrate a thousand times a second, and the pitch of the note that we hear coming from it will be exactly the same as the pitch of the note at the transmitting station which produced the alternating signal current in the receiver.

The strength of this vibration, that is, how much the diaphragm is bent during each vibration, depends on the *strength* of this alternating signal current. So, if we have an audio-frequency current coming out of the receiver which corresponds to the voice sounds or musical sounds we are receiving, the diaphragm of the loud-speaker unit will vibrate in just the same manner. And the air in front of the diaphragm will also vibrate in the same manner, both as regards *frequency* and *intensity*, and these will be air waves or sound waves, which we will hear.

Many loud-speaker units are made this way, and all headphones are made this way. There is another way in which loud-speaker units are often made, however, which we will now study. In one of your previous lessons you learned that when a coil of wire carried a current, the coil could act just like a magnet. In other words, the current flowing in the coil establishes a magnetic field, which can attract iron just like a permanent magnet. It should be possible therefore to replace the permanent magnet shown in Fig. 16, by an *electromagnet,* that is, a coil carrying an electric current.

This arrangement is shown in Fig. 19. At the bottom of this figure is shown the magnetizing coil (C), or electromagnet, which takes the place of the permanent magnet of Fig. 16. But you must know that this coil is wound on a soft iron core, (I), whereas a permanent magnet is made of hard steel.

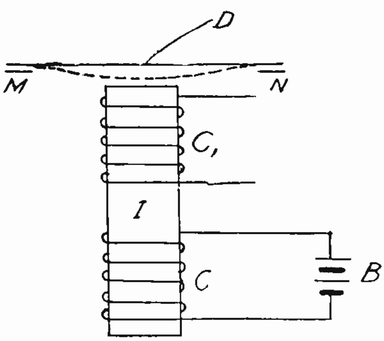


Fig. 19

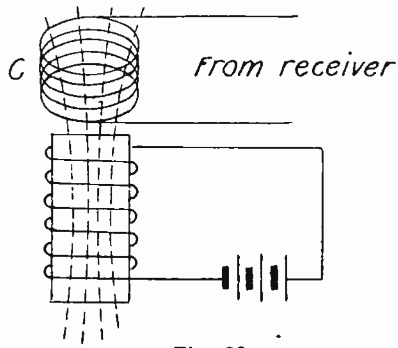


Fig. 20

The reason for this is that hard steel keeps its magnetism a long time, while soft iron does not. In the loud-speaker unit of Fig. 19 we do not want the iron core to keep its magnetism, but to have it magnetized only when the current is flowing in the coils. We shall learn the reason for this later on. There are certain advantages which this type of unit has over the other which we shall also study at the proper time.

Now we can go a step farther, and learn of still a third type of loud-speaker unit. In the units spoken of previously, we had to use an iron diaphragm. It is possible to remove this iron diaphragm by making a coil do its work. Suppose we have some kind of a magnet, such as a permanent magnet or an electromagnet. In Fig. 20, for the sake of illustration, we have shown an electromagnet, although a permanent magnet would work. Suppose also that we have a coil placed in the magnetic field of this magnet. This coil is marked C in Fig. 20. Now suppose that this coil is connected to the output of a radio receiver so that the alternating signal current will pass through it. This connection is made by means of flexible wires, so that the coil C is free to vibrate. The coil is held in position by means of a light spring, which is not shown in Fig. 20.

Now, when the signal current coming from the receiver passes through the coil C, it will establish an alternating magnetic field. It is, therefore, plain that the coil C will vibrate up and down just like the diaphragm, for at one instant the field of the coil C will aid the field of the electro-

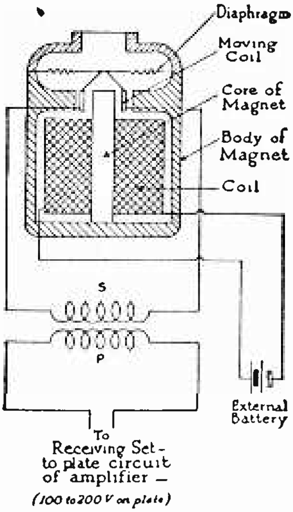


Fig. 21—Moving Coil (Electrodynamic) type of Loud-Speaker Unit.

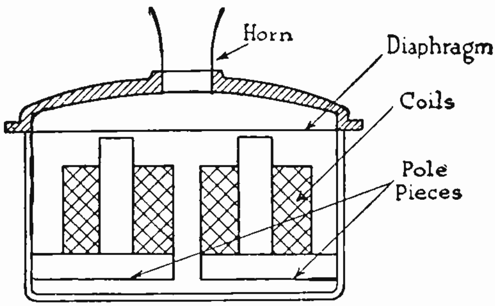
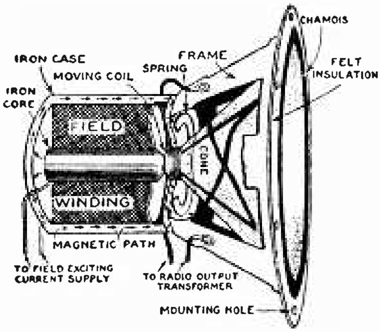


Fig. 22—Ordinary Telephone Receiver Type of Loud-Speaker Unit Showing Pole Pieces, Coils and Diaphragm.

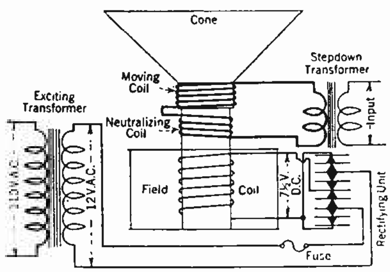
magnet, and at the other instant the combined field will be made much stronger.

To make this type of unit work, all that we have to do is to fasten a light rod to the coil C and at the other end of this rod fasten some kind of a "pusher,' which will make the air vibrate in front of it. This *pusher* may be a small diaphragm of mica, or it may be a large cone of paper. In Figure 21 we have shown a unit of this type known as the electrodynamic speaker. The illustration shows a cross-section of the unit, that is, how it would appear if it were cut right through the middle. The magnetizing coil is marked with crossed lines; it is a coil of many turns of wire, and is connected to a battery of 6 volts. This furnishes the steady or constant magnetic field for the unit. It is represented by the lower coil in Fig. 20.

Inside of the magnetizing coil is a core of iron. Above this magnetizing coil surrounding the iron core is a small coil of wire, very light in weight, which is connected to the output of the radio receiver. This is the coil that vibrates up and down in the magnetic field. It is called the "voice-coil," and is represented in Fig. 20 by the upper coil, marked C. It is supported rigidly by means of a "spider" or "tripod," and the spider and coil are attached to the diaphragm. As the coil vibrates up and down the diaphragm is thus caused to vibrate.



The Mechanical Construction of an Electrodynamic Speaker Unit For a Free-Edge Cone. The Paper Cone is Attached to the Moving Coil.



(Courtesy of Radio Broadcast).

Circuit Diagram of an A. C. Dynamic Speaker Unit Showing Connections to Transformers and Rectifier Unit.

Fig. 23

There are several variations of this type of loud-speaker unit; in one of them the diaphragm is replaced by a large paper cone. Figure 23 shows two types of electrodynamic speakers.

It will be well at this point to obtain a clear understanding of the various terms applied to different types of loud-speakers. In the first place, we must always have a steady magnetic field in the unit. This may be furnished either by a permanent magnet of steel or by an electromagnet such as shown at C, in Fig. 19.

Next, there is always required a "voice-coil," as we termed it above. It is the coil into which the alternating signal current from the radio receiver is passed. In the diaphragm type of unit this voice-coil is fixed, that is, it does not move, but operates the loud-speaker by virtue of its *magnetic attraction* on the diaphragm. Hence, this type of speaker is called the *magnetic* type. This is true regardless of whether the steady magnetic field is furnished by a permanent magnet or by an electromagnet.

In the electrodynamic speaker, the voice-coil itself moves; this is a condition somewhat analogous to the rotation of the armature of a motor in the magnetic field of the field winding.

To sum up then, the terms magnetic and electrodynamic merely means whether the voice-coil acts on a diaphragm or whether it does the moving itself. The term *electromagnetic* applies only to the method of obtaining the steady field from a coil and battery instead of a permanent magnet.

Electromagnets have many advantages over permanent magnets. They consist of coils of many turns of wire wound over cores of soft iron. With magnets of this type, it is possible to produce a field of great strength, such as is required for the reproduction of strong radio signals.

Next we come to the subject of horns; this is a very difficult problem, and there is still a great deal to be learned about them. The main object of the horn is to enable the loud-speaker unit to work on a *large* quantity of air all at once. You can easily see that if we had to be satisfied with allowing a small diaphragm about 3 inches in diameter to act on the air, we would not get much volume out of the loud-speaker. In the case of ear-phones, which are clamped very close to the ear, it is possible to obtain sufficient volume, but when we want the sounds to fill a complete room, we have to make the loud-speaker unit move quite a large quantity of air.

The simplest way in which to do this is to fasten a horn or a bell over the diaphragm. Such an arrangement is shown in Fig. 22. It is done by placing the unit in a case of some kind, and then covering the diaphragm by a cap which screws on the casing. The horn or bell is then screwed into this cap.

There are many ways of constructing loud-speakers, but we cannot go into detail concerning their construction here. In all of them, however, the aim is to obtain as great volume as possible, and also to make this reproduction as accurate as possible.

This is about as far as we can go in this bird's-eye view of radio in the matter of loud-speakers. You have at least learned how they operate, and a few other important things about them. We will study them in detail later on in another lesson of this course.

There has been a great deal of information included in this lesson, but we feel sure that you will be able to get all of it. *The better you learn this lesson, the easier it will be for you in the lessons that follow.* This is especially true of the first six lessons, which as we have said before, will give you a comprehensive or bird's-eye view of the whole matter of radio receivers and all that goes with them.

TEST QUESTIONS

Number your Answer Sheet 5—3 and add Your **Student Number**

Never hold up one set of lesson answers until you have another set ready to send in. Send each lesson in by itself before you start on the next lesson.

In that way we will be able to work together much more closely, you'll get more out of your course, and better lesson service.

1. Draw a diagram of a resistance coupled audio-frequency amplifier.
2. What is the size of the resistance in the plate circuit and the capacity of the blocking condenser recommended for a resistance coupled amplifier?
3. What is an impedance coil?
4. Draw a diagram of an impedance coupled audio-frequency amplifier.
5. What is the one common defect in transformer and impedance coupled amplifiers?
6. Name three different "B" battery voltages that may be used with the 201-A tube and the corresponding "C" battery voltages that should be used.
7. What is the advantage of using regeneration?
8. Draw a circuit diagram of a regenerative receiving set.
9. Name one way of controlling regeneration in a radio-frequency amplifier.
10. What is the advantage of using a magnetizing coil instead of a permanent magnet in a loud-speaker unit?

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